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Final Scientific Report to Air

Force Office of Scientific Research

Contract AFOSR 76-3050

DESIGN OF EXPERIMENTS AND RELIABILITY MODELS

August 31, 1980

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University of Illinois

Chicago, Illinois 60680

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I.   INTRODUCTION

This is a summary of scientific achievements and activities sponsored by U.S. Air Force Office of Scientific Research under contract AFOSR 76-3050 as of August 31, 1980.

Our research efforts have been concentrated on two main areas: Design of experiments and Reliability. In the area of design of experiments we have studied problems of data collection relevant to virtually all Air Force technical areas. There is a strong need in the Air Force to reduce costs and save time in the collection of large amounts of data. The reduction in costs and time should be done clearly without any damage to the statistical quality of the data being collected. Our research problems not only add to our store of knowledge about multifacet of data collection and data analysis in general, but they have immediate applications to many important problems which the United States Air Force is faced with. In the area of reliability our efforts have been mainly directed towards developing comprehensive treatments of various reliability models which have useful applications in determining and improving levels of performance and reliabilities of complex systems and their components. These models include:

(i) A simple model in structural reliability which has applications in various areas such as inventory depletion, urn models, etc.;

(ii) Multivariate life distributions useful in modeling system with dependent components, and

(iii) Multistate (Degradable) Coherent Systems. (KR)

In addition to the above models we have also investigated under this grant some other problems which can have useful applications in some aspects of reliability. These problems include:

(iv) A relationship between partial derivatives of the reliability function of a coherent system and its minimal path (cut) sets.

(v) Unified treatment of some inequalities among ratios of means.

(vi) Characterizations of discrete classes of life distributions using
order statistics.

Our efforts under the present contract have been and are continuing to be
very fruitful in yielding many useful and interesting results. This is
demonstrated by the list of accomplishments detailed in the following section.

II. RESEARCH ACCOMPLISHMENTS

Our research activities during the past four years, since the inception of
the grant AFOSR 76-3050 in July 1976, can be classified into five broad
categories:

A. Production of thirty-nine research reports;

B. Production of three Ph.D. dissertations;

C. Production of an advanced book;

D. Organizing and editing a special issue on optimal design of
experiments;

E. Presenting research results at international conferences held in the
U.S. and abroad.

We shall now explain in some detail our effort in each of the five
categories.

A. Production of thirty-nine scientific reports.

In this category we have produced thirty-nine scientific reports--the status
of their publications in professional journals are as follows: Eleven of these
reports are already in print, eleven reports have been accepted for publication,
twelve reports are under consideration for publication, and the remaining five
reports are under revision for possible publication. These reports are:

1. Foody, W. and Hedayat, A. On theory and applications of BIB designs
with repeated blocks. Ann. Statistics 5, 932-945 (1977).

2. Hedayat, A., Raktoe, B.L. and Talwar, P.P. Examination and analysis of residuals: A test for detecting monotonic relation between mean and variance in regression through the origin. Communications in Statistics--Theory and Methods A6, 497-506 (1977).

3. Hedayat, A. A complete solution to the existence and non-existence of Knut Vik designs and orthogonal Knut Vik designs. J. Combinatorial Theory (A) 22, 331-337 (1977).

4. Hedayat, A. and Afsarinejad, K. Repeated measurements designs, II. Ann. Statistics 6, 619-628 (1978).

5. Hedayat, A. A generalization of sum composition: Self orthogonal Latin square design with sub self orthogonal Latin square designs. J. Combinatorial Theory (A) 24, 202-210 (1978).

6. Hedayat, A. and Wallis, W.D. Hadamard matrices and their applications. Ann. Statistics 6, 1184-1238 (1978).

7. Hedayat, A. Sampling designs with reduced support sizes. In: Optimizing Methods in Statistics (J. Rustagi, Ed.) pp. 273-288 (1979), Academic Press.

8. Ash, A. and Hedayat, A. An introduction to design optimality with an overview of the literature. Communications in Statistics (A7), 1295-1325 (1978). [Special issue on optimal design theory].

9. Sclove, S. Testing independence of variates in an infinitely divisible random vector. J. of Multivariate Analysis 8, 479-485 (1978).

10. Hedayat, A. and Li, Shuo-Yen Robert. The trade off method in the construction of BIB designs with variable support sizes. Ann. Statistics 7, 1277-1287 (1979).

11. Hedayat, A. and Khosrovshahi, G.B. An algebraic study of BIB designs: A complete solution for v=6 and k=3. J. Combinatorial

Theory (A), to appear.

12. Hedayat, A. and Li, Shuo-Yen Robert. Combinatorial topology and the trade off method in BIB designs. _Proc. of International Symposium on Combinatorial Mathematics and Optimal design_. (Held in Colorado State University during June 5-9, 1978), to appear in _Ann. of Discrete Mathematics_.

13. Hedayat, A. and Kageyama, S. The family of t-designs: I _J. of Statistical Planning and Inference_. (To appear).

14. Hedayat, A. On Theory of trade off and its application to the construction of BIB designs with variable support sizes. Technical Report, Department of Mathematics, University of Illinois, Chicago (1977).

15. Hedayat, A. and Li, Shuo-Yen Robert. On theory of trade off and its application to the construction of BIB designs with variable support sizes. Technical Report, Department of Mathematics, University of Illinois, Chicago (1977). _Remark:_ This technical report extends the results of report 10 above.

16. Hedayat, A. On Scheffe's S-method. A review. (1977). submitted for publication.

17. Kageyama, S. and Tsuji, T. A condition for the validity of Fisher's inequality. Technical Report, Department of Mathematics, University of Illinois, Chicago (1977). Submitted for publication.

18. Sclove, S. Infinitely divisible distributions in statistical inference. Technical Report, Department of Mathematics, University of Illinois, Chicago (1977).

19. Sclove, S. Two-dimensional markov processes. Technical Report, Department of Mathematics, University of Illinois, Chicago (1977).

20. Magda, C. and Hedayat, A. Repeated measurements designs, III Technical Report, Department of Mathematics, University of Illinois, Chicago (1978).

Submitted for publication.

21. Ash, A. Generalized Youden designs: Constructions and tables. ;
Technical Report, Department of Mathematics, University of Illinois,
Chicago (1978). Submitted for publication.

22. Magda, C.G. Circular balanced repeated measurements designs.
Technical Report, Department of Mathematics, University of Illinois,
Chicago (1979). To appear in Communications in Statistics.

23. Hedayat, A. and Magda, C.G. Repeated measurements designs, IV.
Technical Report, Department of Mathematics, University of Illinois,
Chicago (1979). Submitted for publication.

24. Magda, C.G. Some E-optimal block designs. Technical Report, Department
of Mathematics, University of Illinois, Chicago (1979). Submitted
for publication.

25. El-Neweihi, E. Extensions of a Simple Model with Applications in
Reliability, Extinction of Species, Inventory Depletion and Urn Sampling.
Communications in Statistics Series A9, 399-414 (1980)

26. Hedayat, A. Schur optimality in design of experiments. Proceedings of
the Fifth International Conference on Statistics, Computer Science and
Social Research (Held in Cairo, Egypt during 3/28-4/6, 1980), to appear.

27. Constantine, G.M. and Hedayat, A. Construction of PBIB designs with
triangular and L_2 schemes. Technical Report, Department of Mathematics,
University of Illinois, Chicago (1980). Submitted for publication.

28. El-Neweihi, E. A Relationship between Partial Derivatives of the
Reliability Function of a Coherent System and its Minimal Path (Cut)
Sets. Mathematics of Operations Research, to appear.

29. El-Neweihi, E. and Proschan, F. Unified Treatment of Inequalities Among
Ratios of Means, Proc. of Amer. Math. Soc. To appear.

30. El-Neweihi, E., Proschan, F. and Sethuraman, J. A Multivariate New
Better Than Used Class Derived From a Shock Model, Mathematics of

Operations Research. Submitted June, 1980.

31. El-Neweihi, E. Stochastic Ordering and a Class of Multivariate New Better Than Used Distributions. Communications in Statistics Series A, to appear.

32. El-Neweihi, E. Multistate Reliability Models: A Survey. Proc. of the Fifth International Conference on Statistics, Computer Sciences and Social Research. (Held in Cairo, Egypt 3/28-4/6, 1980), to appear.

33. El-Neweihi, E. Multivariate New Better Than Used Processes, in preparation.

34. Hedayat, A. and Lin, B.Y. Controlled probability proportional to size sampling designs. Technical Report, Department of Mathematics, University of Illinois, Chicago (1980). Submitted for publication.

35. Hedayat, A. Study of Optimality criteria in design of experiments. Proceedings of International Symposium on Statistics and Related Topics (Held in Carleton University during May 5-8, 1980), to appear.

36. Constantine, G.M. On Schur Optimality. Technical Report, Department of Mathematics, University of Illinois, Chicago (1980). Submitted for publication.

37. Hedayat, A. and Hwang, H.L. A computer algorithm for generating a basis of the trades on t-designs. Technical Report, Department of Mathematics, University of Illinois, Chicago (1980). Submitted for publication.

38. Constantine, G.M. Upper bounds on the number of spanning trees in a simple graph. Technical Report, Department of Mathematics, University of Illinois, Chicago (1980). Submitted for publication.

39. Hedayat, A. and Lin, B.Y. A complete class theorem for probability proportional to size sampling designs. Technical Report, Department of Mathematics, University of Illinois, Chicago (1980). Bulletin of Institute of Math. Statistics. To appear.

AN OVERALL VIEW OF OUR RESEARCH

In performing research we have always kept the applicability of our results in mind. We have never generalized or extended a result without justifying the practical importance of the problem under consideration.

The results we have obtained may not be accessible to practitioners with limited knowledge of the subject at hand. In our formal publications we had to be very technical. While such publications will be easily accessible to research workers in the area, it would certainly be very hard, if not impossible, to be understood by practitioners. To overcome this deficiency we are preparing nonformal versions of our results understandable to non-specialists. As of today, we have prepared three catalogs of designs of practical sizes in the area of BIB designs with repeated blocks and repeated measurements designs.

B. Production of three Ph.D. dissertations

Three research assistants have completed their Ph.D. dissertations under the direction of A. Hedayat. These are:

1. Ash, Arlene S.

   Construction of generalized Youden design.

2. Magda, Constantine G.

   On E-optimal block designs and Schur optimality.

3. Foody, Walter M.

   Properties, Construction, and application of BIB designs with repeated blocks.

C. Production of a book

With the collaboration of W.T. Federer from Cornell University (United States), and B.L. Raktoe from the University of Guelph (Canada), we have prepared an advanced book entitled Factorial Designs. This book will soon appear in Wiley Series in Probability and Mathematical Statistics.

This book has been prepared with the following goals in mind:
(i) Providing the researchers with a complete and unified theory in the area of factorial experiments; and (ii) providing the practitioners with up-to-date applicable results in the area of multifactorial experiments.

D. Organizing and editing a special issue on optimal design of experiments

Since our research activities are mainly in the area of scientific designs we found it important and indeed essential to organize a special issue on optimal design of experiments. Distinguished researchers from the United States, England, Germany, and the U.S.S.R. were invited to contribute for the special issue. The collection of papers has appeared as a special issue of Communications in Statistics, Volume A7, No. 14, under my editorship in December, 1978. The contributions and the title of their papers are:

1. Ash, A. and Hedayat, A. (Boston University and University of Illinois). An introduction to design optimality with an overview of the literature.

2. Cheng, Ching-Shni. (University of California, Berkeley). A note on (M,S) optimality.

3. Fedorov, V.V. (Moscow State University). Some problems in designing discriminating experiments.

4. Kiefer, J. (Cornell University). Asymptotic approach to families of design problems.

5. Kurotschka, V. (Free University of Berlin). Optimal design of complex experiments with qualitative factors of influence.

6. Silvey, S.D., Titterington, D.M. and Torsney, B. (University of Glasgow). An alogrithm for optimal designs on a finite design space.

7. Studden, W.J. (Purdue University). Designs for large degree polynomial regression.

8. Wu, Chien-Fu. (University of Wisconsin). Some iterative procedures
    for generating non-singular optimal designs.

E. <u>Presenting research results at international conferences held in the
    U.S. and abroad</u>

As invited speakers, we presented our newly discovered results at the
international meetings sponsored by the Institute of Mathematical Statistics,
the American Statistical Association and the International Statistical
Institute. We also presented invited papers at the International Conference
on Optimization in Statistics held at the Indian Institute of Technology in
Bombay, International Symposium on Combinatorial Mathematics and Optimal
Design held in Colorado State University, Fifth International Conference on
Statistics, Computer Science and Social Research held in Cairo, Egypt, and
International Symposium on Statistics and Related Topics held in Carleton
University, Canada. Participation in these meetings was quite stimulating as
we were able to discuss in person with other scientists around the world, the
results and the difficulties in pursuing our research. Through these meetings
it has become possible to generate an informal line of communication with
other researchers from universities in the United States and other countries--
such informal contacts are essential in pursuing our research.